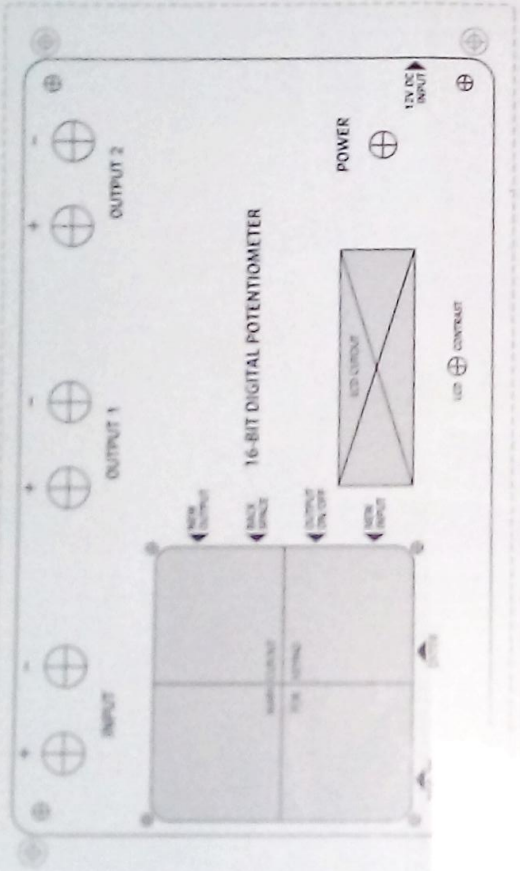
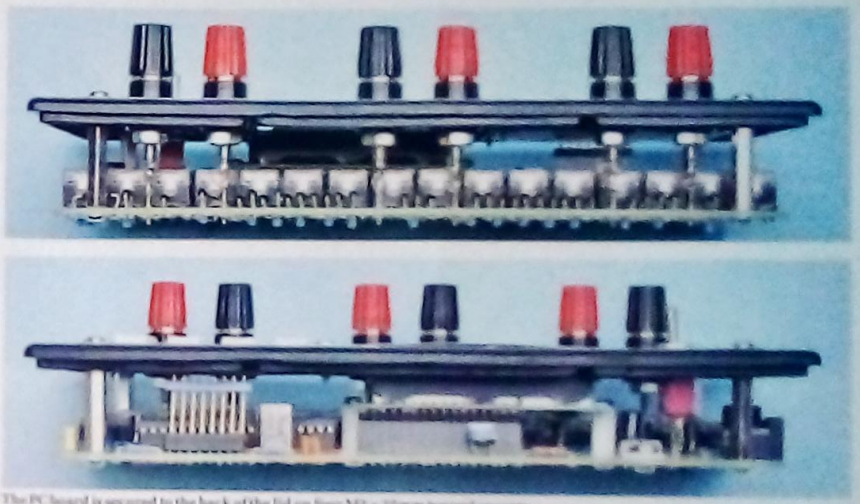




The PC board is secured to the back of the lid on four M3 × 25mm tapped spacers, with the keypad's SIL pin header plugging into a matching socket. Ignore the resistors shown on the copper side of the PC board – this is a prototype and all resistors go on the top of the board in the final version.

using either a few spots of contact cement or strips of adhesive tape around the edges.

Once it's in place, attach the four M3 × 25mm spacers to the rear of the lid using M3 × 6mm machine screws. Don't tighten these screws completely just yet though, because the spacers may need to be moved slightly when mounting the PC board assembly.

This next step is slightly tricky. That's because you need to make sure that the 'extension wires' attached to switch S1 and the six binding posts pass through their matching holes in the board. At the same time, the pins of the 8-way SIL strip attached to the keypad must go into the matching header socket. This isn't all that difficult to do, but you do need to be both careful and patient to get it right.

Push the board down until it rests on the spacers, then secure it using four more M3 × 6mm machine screws. The screws attaching the spacers to the front panel can then be tightened, after which the complete assembly can be upended and the various extension wires soldered to their pads on the board.

Your new *16-Bit Digital Potentiometer* is now complete.

Checkout time

All you need for the initial checkout is a source of 12V DC capable of supplying 400mA or more. This can be either a 12V battery or a suitable mains plugpack. Fit a 2.5mm DIN cord assembly to its output lead (positive to the centre pin) and plug it into CON1.

When you switch the power on via S1, you should be greeted by a warm yellow glow from the LCD module's backlighting. You should also see the initial greeting message, ie, "16-Bit Digital Potentiometer". If this is illegible or clearly, adjust trimpot VR1 with a small screwdriver to set the LCD contrast for optimum contrast.

At the first test, you should find that the message displayed has changed to "Output = OFF" on the bottom line. Output = 10.000V" on the bottom line. This shows the default start-up settings, with the divider relays all turned off, so there is zero output and the electronic pot for an attenuation of unity (ie, 1).

If everything checks out so far, try pressing the keypad's 'C' (output toggle) key for about 500ms. This should

capacitors. Most of the capacitors are relatively low-value unpolarised ceramic or metallised polyester types. The only two polarised capacitors are the 470µF and 220µF electrolytics, both of which go in at lower right. Make sure you fit these the correct way around.

Now you can fit DC input socket SCON1, the 40-pin socket for IC1 and the 16-way SIL socket for making the connections to the LCD module. Also fit an 8-way length of SIL socket strip for the keypad connections, at lower left on the board.

Power transistors Q1 to Q16 are next. They must be orientated as shown in Fig.4, after which you can install crystal X1. Solder the crystal's leads quickly, so that it doesn't get too hot.

Regulator REG1 can now go in. It mounts flat on the board, with its leads bent down by 90° about 4mm from its body. Secure it to the PC board using an M3 × 6mm screw and nut before soldering its leads (warning: don't solder the leads first, otherwise you could crack the PC board tracks as the mounting screw is tightened down).

Once the regulator is in place, install the 16 mini relays (RLY1 to RLY16). These have a polarised pin layout, so they can only be fitted one way around.

Precision resistors

The 'precision' resistors in the ladder network all fit along the top edge of the board, above the relays. There are 32 of these in all, consisting of two different values: 1.000kΩ (0.1%) and 1.500kΩ (0.1%). Fit the 16 × 1.000kΩ resistors first, followed by the 17 × 1.500kΩ resistors.

It's a good idea to fit the 1.000kΩ and 1.500kΩ resistors with their bodies a couple of millimetres above the board. This will help ensure that the resistors are not overheated when their leads are being soldered to the copper pads underneath. You should also solder the solder joints quickly, to minimise the risk of heat damage.

As mentioned previously, if you are unable to obtain 1.000kΩ 0.1% resistors, you can use 1.010kΩ 0.1% resistors instead. These must then each have a 910kΩ 1% resistor connected in parallel, to trim the values back to 1.000kΩ. Install these 910kΩ resistors only if necessary (they are shown dashed on Fig.3).

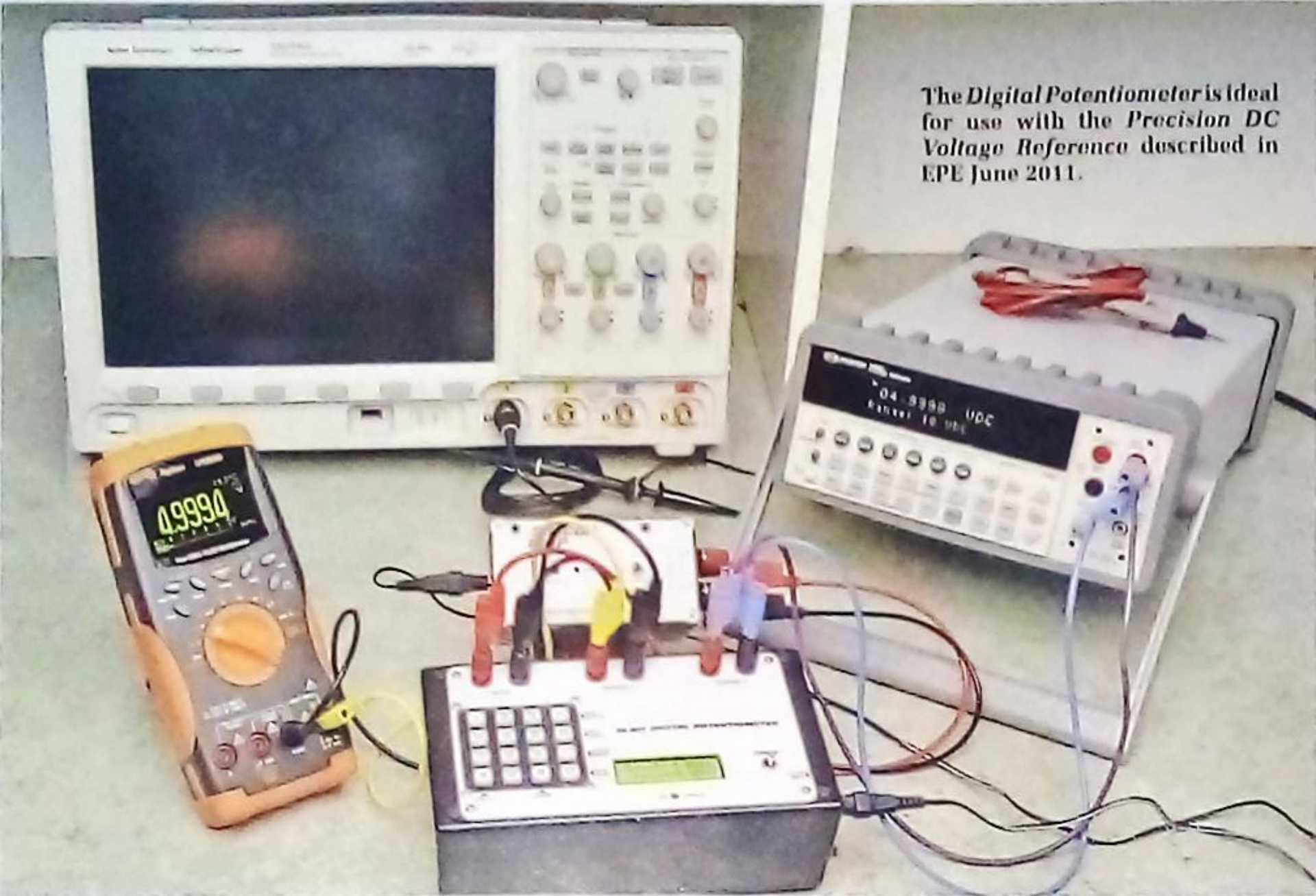
You can purchase 1.010kΩ resistors from either Farnell (Cat. 1681809, 9101488 or 1715404) or RS Components (Cat. 166-2235).

LCD module

The only remaining component to install (apart from the PIC) is the LCD module. To do this, first attach two M3 × 15mm tapped nylon spacers to the main PC board at the indicated mounting positions. These spacers can be secured using M3 × 6mm machine screws, passing up from underneath.

Next, plug the long ends of a 16-way SIL pin header strip into the SIL socket just above trimpot VR1, pushing the pins in as far as they'll go. The LCD module is then to be fitted in position, with the top ends of the SIL header pins passing through the holes in the lower edge of the module.

Push the LCD module all the way down so that it sits against the spacers, then secure it using another two M3 × 6mm machine screws. A fine-tipped soldering iron must be used to solder all 16 pins of the SIL header to the tiny copper pads along the top edge of the LCD module.



The *Digital Potentiometer* is ideal for use with the *Precision DC Voltage Reference* described in EPE June 2011.

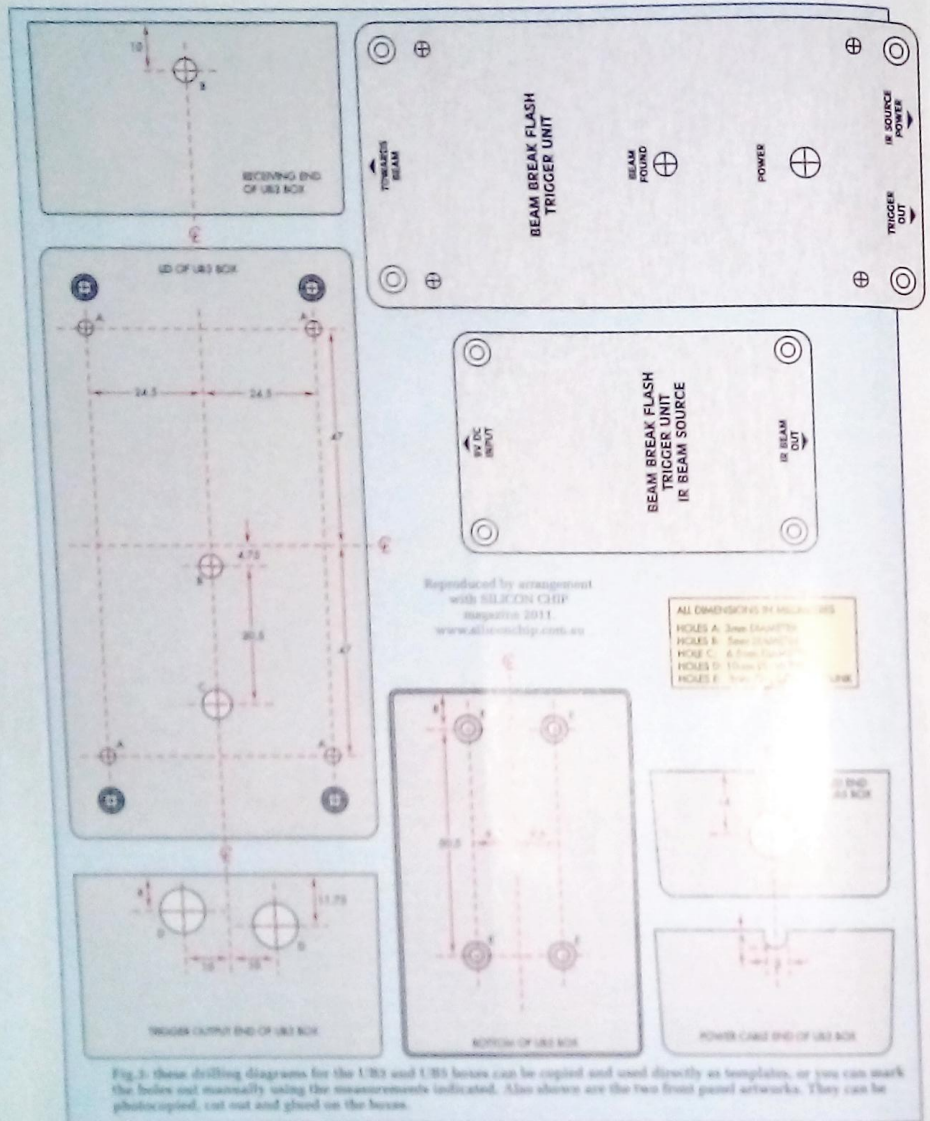


Fig.3: these drilling diagrams for the UB3 and UB5 boxes can be copied and used directly as templates, or you can mark the holes out manually using the measurements indicated. Also shown are the two front panel artworks. They can be photocopied, cut out and glued on the boxes.

The detector board is then ready to be mounted behind the lid of the UB3-size plastic box.

The first step is to drill and ream out the various holes in the lid and ends of the box, as shown in Fig.3. That done, fit a photocopy of the front panel label and cut out the holes using a sharp hobby knife, then secure the board to the lid using four M3 × 15mm tapped spacers and eight M3 × 6mm machine screws.

Note that you'll need to remove the upper nut from the ferrule of switch S1 before doing this, so the ferrule can pass up through its matching hole in the lid. Once the board is in place, the nut can be replaced and threaded down against the top of the lid. The lower nut and lockwasher can then be threaded up against the underside of the lid, using a small spanner.

The next step is to fit a small square of red 'IR transparent' film inside the box behind the single 5mm hole at the IR photodetector diode PD1 end. It can be held in place using a couple of narrow strips of transparent tape, one on either side.

A short 'light hood' is now attached to the photodetector (PD1) end of the box. This must cover the 5mm hole and be as close as possible to concentric with it.

The hood itself can be fashioned from 40mm length of 12mm diameter brass tubing (see photos) or from a similar length of opaque (preferably black) PVC conduit. Whichever you use, it's simply glued to the end of the box using 5-minute epoxy cement.

Now for the final assembly. First, solder the battery-snap leads to the terminal pins on the underside of the board, then place the battery in the bottom of the box and fasten it in place using either a small aluminium 'U' bracket or a strip of gaffer tape. Finally, cover the lid and PC board assembly into the box before fitting the screws to hold everything together.

Trying it out

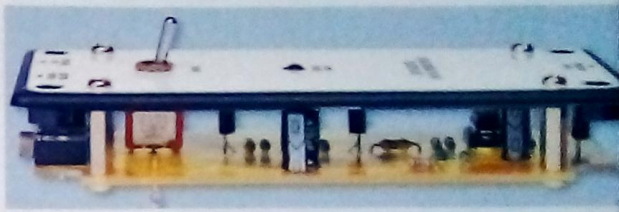
No adjustments are required, so you can try it out simply by plugging the power cable from the IR Source into CON2 on the Detector unit and turning on power switch S1.

If the Detector's light hood is now aligned with the output from the IR Source (or any other source of IR radiation), LED4 should immediately begin glowing. If it does, block the end of the hood with your thumb or a small piece of opaque material and check that the LED immediately switches off.

The same thing should happen if you turn the IR Source away from the Detector, or if you simply block the beam with your hand or some other small opaque object. If this happens, then your Beam-Break Flash Trigger is probably working correctly and is ready for use.

If you're going to be using it in conjunction with the Time Delay Photoflash Trigger unit, all that remains is to make up a suitable cable to connect the two together. This simply involves connecting the Detector's trigger output to the 'external trigger contacts' input (CON4) of the delay unit.

The Beam-Break Flash Trigger should give reliable triggering with the IR Source unit placed up to a metre or so from the Detector box in normal room lighting. This 'beam length' range can be extended considerably in dark (eg, night-time) conditions, but in bright sunlight it will be shortened due to the relatively high level of IR in the ambient light. *EPE*



Above: the Detector board is secured to the lid of the UB3 case using four M3 x 15mm tapped spacers and eight M3 × 6mm machine screws

Left: a 'light hood' is fitted to the end of the Detector unit to prevent interference from stray IR light sources.

Direct flash triggering: making the cable

As mentioned in the article, the Beam-Break Flash Trigger can also be used to trigger an electronic flash directly, rather than via the Time Delay Photoflash Trigger. To do this, trigger output CON3 is simply connected to the photoflash via a suitable cable.

However, when you're making up this cable, make sure that the positive side lead from the flash input is connected to the centre contact of the plug that goes to CON3. If the polarity is reversed, MOSFET Q3 in the Beam-Break Flash Trigger could be damaged.

The procedure is to first use your DMM to check the polarity of the voltage at the end of the cable that's plugged into the flash unit (ie, with the flash unit powered up and ready for triggering). Once that's done, you'll then know which way round to connect the cable to the plug that goes to CON3 on the Detector unit.

While you're checking the polarity of the cable leads, make a note of the actual voltage itself. If it is below 60V, that won't be a problem. Conversely, if it's higher than 60V, you'll need to replace the 2N7000 MOSFET with one having a higher voltage rating – such as an IRF540N.

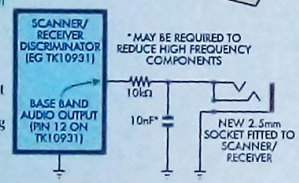
CONVERTING UNIDEN SCANNERS FOR AIS

THESE well-priced, wide-coverage and very popular handheld scanners offer a valuable 'close call' feature and have become well respected for general VHF/UHF work.

The discriminator tap access is straightforward and fitting an external socket should make for a neat and professional enhancement to the set. However, your scanner warranty may become invalid!

All variants of the UNIDEN UBC72/73 and 92/93 use the 24-pin TOKO TK10931 discriminator IC, with baseband audio output at pin 12 (LND7). This accesses the unfiltered audio. A resistor soldered to a convenient pad on the PC board provides the tap without otherwise affecting scanner operation. In most cases, a 10kΩ resistor suffices, but with some sound cards we've had to go as high as 220kΩ to avoid overload. You could also use a 220kΩ trimpot in series with a 10kΩ resistor to make adjustment easier.

The basic setup for receiving the ~160MHz AIS signals and decoding them via your PC's sound card.

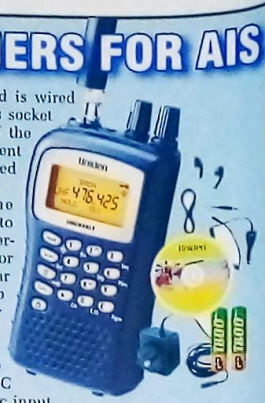

SCANNER/ RECEIVER DISCRIMINATOR (EG TK10931)
BASE BAND AUDIO OUTPUT (PIN 12 ON TK10931)
* MAY BE REQUIRED TO REDUCE HIGH FREQUENCY COMPONENTS
10kΩ
10nF*
NEW 2.5mm SOCKET FITTED TO SCANNER/ RECEIVER

Tapping into the receiver's unfiltered audio is quite simple. At right is the circuit diagram suiting the Uniden scanner.

The resistor's other end is wired to a 2.5mm mono chassis socket mounted on the back of the scanner. There is sufficient space between the stacked PCBs and case for this.

A short wire for the ground lead can be run to the antenna's ground terminal – a 10nF capacitor between the resistor's far end and ground may help remove residual higher frequency portions.

A 2-wire external lead then connects to a stereo 3.5mm plug to suit the PC soundcard's line-in or mic input socket. The scanner squelch must be wide open ('hissing') but the scanner's internal speaker volume can be turned right down.

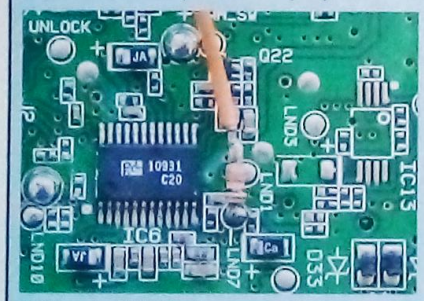


The antenna

Unlike 2.4GHz WiFi, VHF marine signals are not *so* influenced by nearby obstructions, but the best AIS reception will still be gained with clear line-of-sight (LOS) coverage.

The supplied 'rubber ducky' whip antenna on most scanners should allow open-terrain AIS reception to perhaps 6nm (nautical miles) (~10km), but either elevation or a better antenna (or both) will greatly assist – it really depends on your proximity to nearby shipping.

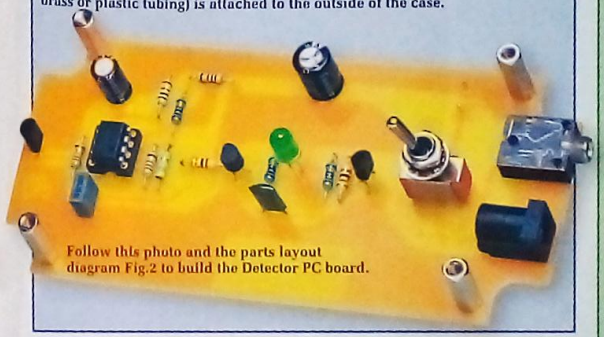
The BNC socket on most scanners readily allows modest coax runs to [illegible] antennas, but a simpler and more portable [illegible] signals come from [illegible]



Undoing six Philips-head screws readily dismantles the Uniden scanner and the revealed circuit boards simply clip apart. Neatly solder the 10kΩ resistor and outlet wire at LND7, perhaps sliding fine heat shrink tubing over the wire joint to prevent circuit board shorts.

To prevent confusion with the scanner's fitted 3.5mm headphone socket, the output socket to the computer sound card should be an open-type 2.5mm mono socket (eg. Jaycar PS-0105), as modern enclosed types are slightly too long for the most suitable rear case hole position.

An infrared transparent filter is fitted to the inside of the case at the receiving (PD1) end of the UB3 box, while a 30mm × 12mm-diameter 'light-hood' (eg, brass or plastic tubing) is attached to the outside of the case.



Follow this photo and the parts layout diagram Fig.2 to build the Detector PC board.

in Fig.3. A photocopy can be taken and cut out and glued on the case lid.

Detector board assembly

There are more components on the Detector board, but its construction is still straightforward – see Fig.2. Install the resistors first, taking care to use the correct value at each location. Table 1 shows the resistor colour codes, but it's also a good idea to check each one using a digital multimeter before soldering it in place.

Follow these parts with the metallised polyester capacitors, then fit the two electrolytic capacitors. The latter are polarised, so be sure to orient them as shown. Next, the two PC board terminal pins, used to make the battery connections, can be fitted. **Note that both pins are fitted on the copper side of the board, to make it easier to solder the battery clip leads to them.**

Switch S1 and connectors CON2 and CON3 are next on the list, followed by an 8-pin socket for IC1. Be sure to orient the socket with its notched end towards the adjacent 100nF capacitor, to guide you when plugging in IC1 itself later on.

Transistor Q1, photodetector PD1, MOSFET Q2 and LED4 can now all go in, again taking care to orient them correctly. Note that PD1 is mounted vertically with its curved side facing outwards, and with the centre of its body about 5mm above the PC board. LED4 should also be mounted vertically, with the bottom of its body about 12mm above the board (this ensures that it will protrude slightly from its matching hole in the box lid after assembly).

The Detector board can now be completed by plugging IC1 into its socket (take care with the orientation).

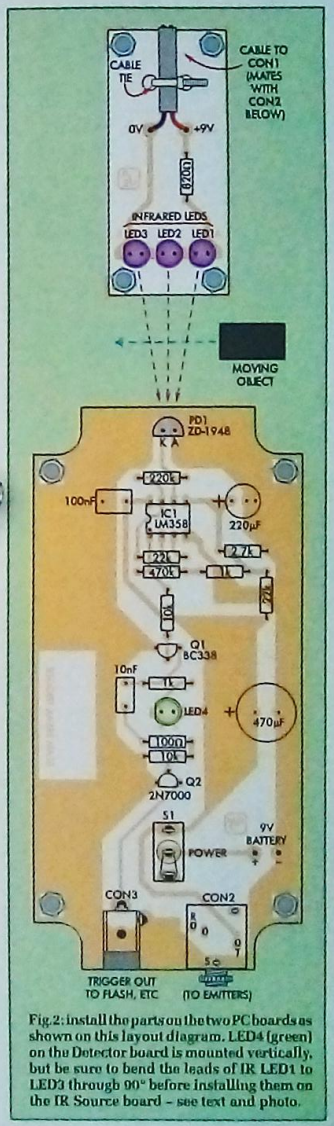


Fig.2: install the parts on the two PC boards as shown on this layout diagram. LED4 (green) on the Detector board is mounted vertically, but be sure to bend the leads of IR LED1 to LED3 through 90° before installing them on the IR Source board – see text and photo.

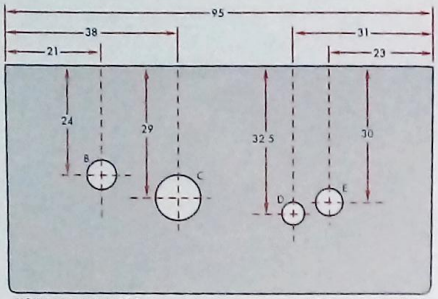


Fig.5: the 'Controls' end of the box showing the cutouts required. Hole B is for the volume pot, C the line out, D is for the power switch and E is for the 12V AC power in.

Trimpots VR2 and VR3 can be mounted now. Potentiometer VR1 may require the shaft to be cut to length to suit the knob. The potentiometer is mounted in position as shown in Fig.4, and is supported using two PC stakes just behind the potentiometer body.

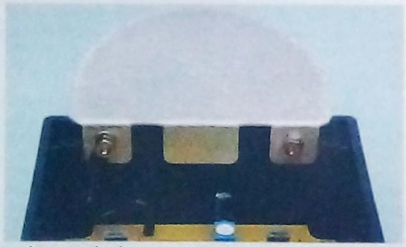
Scrape or file off the passivated coating on the potentiometer body just at the positions where the PC stakes make contact. This will allow the PC stakes to be soldered to the potentiometer body. The soldering holds the potentiometer secure and the lower PC stake earths the potentiometer body to the circuit ground. Attach a nut to the pot-securing thread. This is used as a spacer between the box and pot.

Next, the power socket, switch (S1) and the phono socket can be inserted and soldered in place.

With the PC board complete, you are ready to work on the case. You will need to drill holes in the sides of the box for the DC panel socket, the phono socket and for the antenna-securing screw.

Volume plate

The volume plate is made from 1mm gauge aluminium, shaped as shown in Fig.6. One end is bent over at right angles so it can be secured to the side of the box using M3 screws and nuts. Mark out and drill the holes required in



Looking inside the open case, this photo shows how the volume plate is secured.

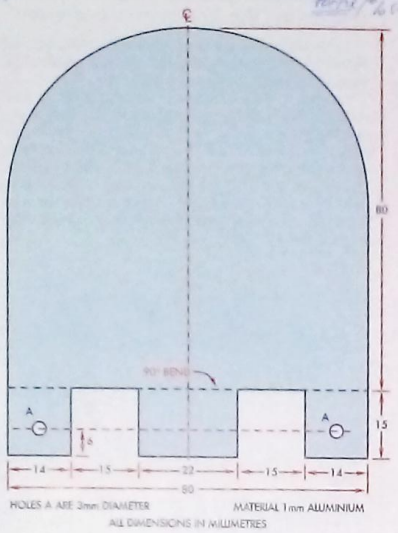


Fig.6: the 1mm-thick aluminium volume plate. Both these diagrams are reproduced same size.

Capacitor Codes

Value	µF value	IEC Code	EIA Code
470nF	0.47µF	470n	474
220nF	0.22µF	220n	224
100nF	0.1µF	100n	104
47nF	0.047µF	47n	473
10nF	0.01µF	10n	103
470pF	NA	470p	471
220pF	NA	220p	221
68pF	NA	68p	68

The mute buttons

There are two additional buttons on the unit – Left Mute and Right Mute. Pressing them toggles the mute status of the corresponding channel at any time. For example, if you press the Left Mute button and the left channel is currently enabled, it will be disabled and vice versa.

The mute status is shown on the status readout and also on each mode readout. For sweep mode, if a channel is muted, an 'l' (indicating the left channel) and/or an 'r' (indicating the right channel) is shown at the top of the display. For the other four modes, a muted channel is shown by changing the minus sign in front of each amplitude setting to an underscore.

If you press the two Mute buttons simultaneously, the left and right channel settings will be swapped. This includes frequency, amplitude and phase (when applicable), as well as the mute status.

Table 1 shows what each generation mode readout looks like by default, and highlights all the settings that can be changed. There is also a description of the function for each setting.

More mode information

As stated in the original article, the output frequency can be set at up to half the sample rate (ie, 48kHz) in steps of 1Hz. Depending on which frequency digit you select with the cursor, pressing the Up and Down buttons will add or subtract 1Hz, 10Hz, 100Hz, 1000Hz or 10,000Hz.

The amplitude is set in similar fashion, and the range is from 0dB to –98dB in 1dB steps.

If you increase the attenuation past –98dB, the readout changes to 'off' and the signal is muted.

Note that as you get close to –98dB, the actual signal amplitudes become so small that the error increases and some values have an identical result. In fact, –96dB, –97dB and –98dB generate the same amplitude due to the 16-bit precision of the scaling factor. However, for attenuation down to –60dB, the scaling is basically perfect. Beyond that, the measured values are as shown in Table 2.

Note that these measurements also include scaling errors from the DAC itself, so they are only a guide as to the unit's actual precision.

Table 1: Signal generation mode readouts

1000Hz –0dB 180° –0dB	Locked Mode readout: top line = signal frequency (both channels) and left channel amplitude; bottom line = channel phase difference and right channel amplitude.
L: 1000Hz –0dB R: 1000Hz –0dB	Independent Mode readout: top line = left channel frequency and amplitude; bottom line = right channel frequency and amplitude.
A: 1000Hz –0dB B: 1000Hz –0dB	Mixed Mode readout: top line = frequency and amplitude of wave 1; bottom line = frequency and amplitude of wave 2.
1000Hz –0dB 100/900ms –30dB	Pulsed Mode readout: top line = frequency (both channels) and pulse-on amplitude; bottom line = pulse-on time (0-9999ms), pulse-off time (0-999ms) and pulse-off amplitude.
20Hz –0dB 20000Hz 10.0/ 1s	Sweep Mode readout: top line = start frequency and amplitude (both channels); bottom line = finish frequency (both channels), sweep time (0.1 - 99.9s) and off-time (0-98s and manual).

Note: values inside green boxes can be selected and varied using the front panel pushbuttons

Keep in mind that when adjusting the attenuation, pressing the Up button increases the attenuation and thus decreases the signal amplitude.

The only other mode settings (aside from frequencies and amplitudes) are time periods. In the case of pulsed mode, they are specified in milliseconds and have a range of 0-9999 (just under 10 seconds) or 0-999 (just under one second). In sweep mode, they are specified in tenths of a second and seconds, with a range of 0-99.9 seconds and 0-99 seconds respectively.

If you switch away from a mode and then back again later, the previous settings are typically retained. However, some are shared between the modes. For example, independent and mixed mode share all their settings, differing only in how they output the signal (independently to each channel or mixed on both). As a result, changing a setting in one changes both.

The left/right channel amplitudes are shared between all modes except pulse and sweep. Most other settings are independent.

Configuration details

Table 3 shows each setting readout and describes each field. Some require more explanation, as follows:

Status readout: the Status readout is very useful in sweep mode. Not only does it show the frequency as the sweep occurs (it's updated four times a second) but also you can pause and restart the sweep. Pressing the Left button in this readout mode pauses or resumes the sweep, while pressing the Right button starts/restarts it.

This is especially useful when you are optimising crossover networks or matching a subwoofer to other drivers. If you hear a peak in the output amplitude, you can pause the sweep and read off the frequency.

There may be times when you want a manual sweep; ie, rather than having it loop repeatedly, you can trigger it manually. To do this, set the sweep off time to maximum via the sweep mode readout – it will show 'man' (manual).

It will then only start when you trigger it manually from the status readout using the Right button.

Sweep setting readout: this allows you to choose between Exponential or Linear sweep. Exponential sweep is the default and is usually what you want. In this mode, the frequency doubles or halves at a fixed rate.

Table 2: Attenuation accuracy

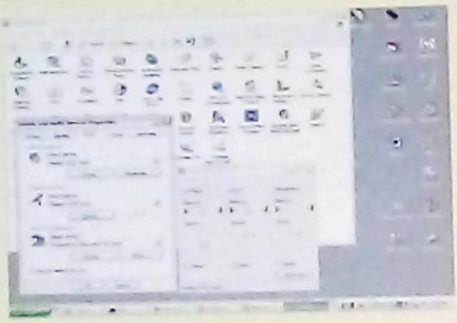
Setting	Measured Value
–60dB	–59.92dB
–70dB	–69.80dB
–80dB	–79.16dB
–90dB	–89.35dB

Displaying the Theremin waveforms

The waveforms on pages 12 and 13 were recorded using Nero Wave Editor. Similar waveforms can be displayed using the NCH Wavepad or Audacity software, or similar.

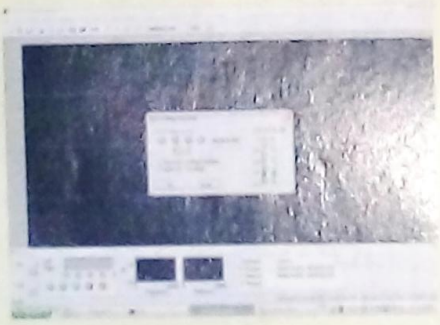
The signal from the Theremin was connected to the line input of the computer. An adaptor lead (phono plug to 3.5mm stereo jack) is required to connect the Theremin output to the computer input. The recording will be in either the left or right channel as the single phono output will only connect to one channel or the other.

In Windows XP, the signal levels are set to prevent clipping of the signal, by selecting <Control Panel>, <Sounds and Audio Devices Properties>, <Sound Recording Volume> and then adjusting the Line In slider.

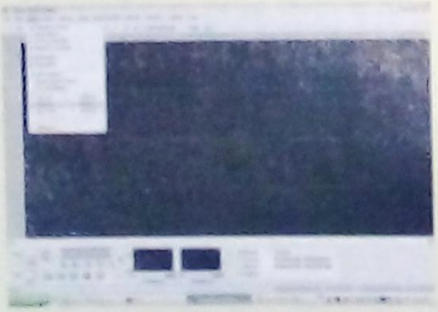


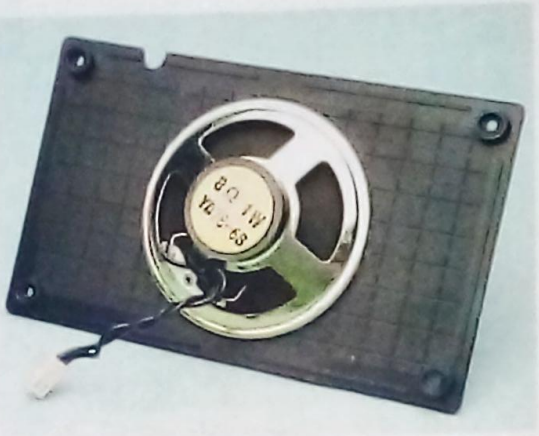
The level meter on the Nero Wave Editor Recording Console shows the signal reading; the volume is set for signal level below the 0dB maximum.

The signal is then recorded using a 16-bit 44.1kHz sample rate.



The recorded signal can then be expanded out to see the waveform in detail using the zoom in feature.





The internal speaker is secured to the lid with silicone sealant or other suitable adhesive.

Secure the PC board to the box with four M3 × 10mm screws into the 9mm standoffs from beneath the box. Attach the four rubber stick-on feet.

Attach the volume disc to the end of the case using two M3 × 10mm screws and nuts and with the eyelet for the volume disc wire clamped under a nut.

The loudspeaker is centrally mounted on the lid, which has a pattern of holes to let the sound out. We used 9 x 6.35mm holes, with one in the centre and eight spaced evenly on a 16mm radius. The loudspeaker is attached to the lid of the case using contact or other suitable adhesive. Before affixing it, make sure that when the lid is placed in position, the speaker terminals face towards the 2-way connector on the PC board.

The loudspeaker is wired to the 2-way header socket on the PC board using two 70mm lengths of hookup wire. A cable tie wrapped around the wire and under the steel speaker frame at the loudspeaker connector will help prevent the wires breaking away from the connector.

Setting up

Once your Theremin is complete, check your work carefully for power and confirm that there is 9V between pin 3 of IC1 and GND (the voltage could range from between 8V and 12V).

Using a suitable alignment tool, wind the ferrite slug for T3 in until there is resistance to movement (*do not force it*). Now count the number of turns to wind it out anticlockwise completely. Set the slug half way between the two extremes.

Volume alignment

You must carry out the volume and pitch adjustments away from the effects of metallic objects, otherwise the Theremin will require retuning when removed from these grounding sources.

Wind the slug for T3 fully anticlockwise and then out again, counting the number of turns. That done, set T3 about 30% of turns anticlockwise. This will set the frequency of the volume oscillator (T3) to below the frequency of the pitch oscillator (T2) to prevent extraneous sounds that can be emitted if the two oscillators are close in frequency.

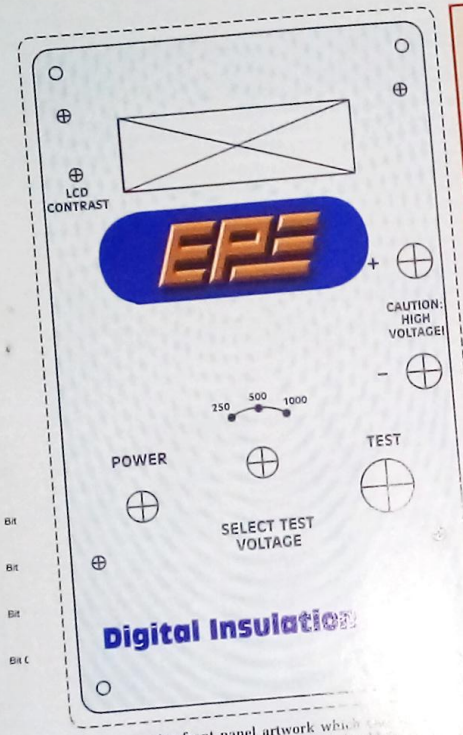


Fig.5: same-size front panel artwork which can be copied and glued to the panel. For protection, it should be covered or sealed with self-adhesive clear plastic.

inside the box spaced only about 1mm from the front.

Once these four holes are drilled and de-burred, you can mount the converter board inside the box using four 12mm-long M3 *nylon* screws, with a *nylon* flat washer and *nylon* nut fitted to each screw first to act as board mounting pillars or 'standoffs'. The converter board can now be slipped down over the screws, and another M3 nylon nut placed on each screw to hold the board in place.

You don't need mounting holes for the batteryholder, because it can be held securely in place using two strips of 'industrial' double-sided adhesive foam tape. However, before it can be fitted [illegible] to accommodate [illegible] cell positions [illegible] end), and then drilling a 2.5mm hole in the end of the sixth cell position, at the negative spring end. The end of the spring is then carefully bent inwards and around in a circle, so that it can be held in place using a 6mm-long M3 machine screw and nut, which will also attach the negative lead connection lug on the outside.

The converted batteryholder can now be fitted inside the main section of the box behind the converter board, with the connection lead side to the left. Mount it using double-sided adhesive foam as mentioned earlier.

The box lid needs several holes drilled, plus a rectangular cutout near the upper end for the LCD. The location and dimensions of all these holes are shown in Fig.5, which can also be used (or a photocopy of it) as a drilling template. The 12mm hole for S2 and the 9mm holes for the test terminals are easily made by drilling them first with a 7mm twist drill and then enlarging them to size carefully using a tapered reamer.

The easiest way to make the rectangular LCD window is to drill a series of closely-spaced 3mm holes just inside the hole outline and then cut between

Insulation testing

Testing the insulation of mains-powered equipment and cables is an important step in ensuring that they are safe to use and don't pose a shock hazard.

According to the Australian and New Zealand standards for safety inspection and testing of electrical equipment (AS/NZS 3760:2003), tests on the insulation of 'domestic' cables and equipment operating from 230V AC should be carried out with a testing voltage of 500V DC.

However, where the equipment includes MOV surge protection devices, the testing can be carried out with a voltage of 250V DC.

The recommended testing voltage for insulation tests on industrial equipment such as ovens, motors and power converters operating from three-phase 400V AC is 1000V DC.

Insulation tests on domestic 230V equipment can be performed by measuring either the leakage current or the insulation resistance.

For Class I (earthed) equipment with accessible earthed metal parts, the leakage current should be no greater than 5mA, except for portable RCDs (residual current devices) where it should not be greater than 2.5mA. The insulation resistance for these devices should be not less than 1MΩ or not less than 100kΩ for a portable RCD.

For Class II (double-insulated) equipment, the insulation resistance with the power switch 'on' measured between the live supply conductors (connected together) and external unearthed metal parts should again be not less than 1MΩ.

The same insulation resistance figure of 1MΩ applies to extension cables and power boards (between the live conductors and the earth conductor), to power packs (between the five input pins and both output connections), portable isolation transformers (between the primary winding and external earthed or unearthed metal parts, between primary and secondary windings, and between the secondary winding and external earthed or unearthed metal parts).

PARTS LIST – DIGITAL INSULATION METER

*1 PC board, code 849 (Main/Dis), 109mm × 84mm
*1 PC board, code 850 (DC-DC Conv), 70mm × 51mm
1 UB1-size plastic box, 157mm × 95mm × 53mm
1 LCD module, 2 lines × 16 characters with LED back-lighting (Altronics Z-7013, Jaycar QP-5512 or equivalent)
1 Ferrite pot-core pair, 26mm OD, with bobbin to suit
1 500mm length of 0.7mm diameter enamelled copper wire
1 8m length of 0.25mm diameter enamelled copper wire
1 100mm length 0.7mm diameter tinned copper wire
1 10× AA batteryholder (flat), cut down to 6×
1 2-pole rotary switch, PC board mounting, with 16mm knob (S1)
1 SPST pushbutton switch, panel mounting (S2)
1 SPDT mini toggle switch, panel mounting (S3)
1 Mini DIL reed relay, SPST with 5V coil
2 Binding post/banana jacks (1 red, 1 black)
2 4mm solder lugs
1 16-pin length of SIL socket strip
1 16-pin length of SIL pin strip
1 18-pin IC socket
2 8-pin IC sockets
4 25mm M3 tapped metal spacers
2 12mm M3 tapped nylon spacers
11 6mm M3 machine screws, pan head
4 6mm M3 machine screws, csk head
3 M3 hex nuts, metal
4 12mm M3 machine screws, nylon
1 25mm M3 machine screw, nylon
9 M3 hex nuts, nylon
6 M3 flat washers, nylon
12 1mm diameter PC board terminal pins

* Available as a pair from the *EPE PCB Service*

Software
All software program files for the *Digital Insulation Meter* will be available from the *EPE* website at **www.epemag.com**.

WE DO NOT SUPPLY READY-PROGRAMMED MICROCONTROLLERS

Semiconductors
1 MC34063A converter controller (IC1)
1 LM358 dual op amp (IC2)
1 PIC16F88 programmed microcontroller (IC3)
1 LM7805 5V regulator (REG1)
1 BC337 *NPN* transistor (Q1)
2 BC327 *PNP* transistor (Q2,Q4)
1 IRF540N 100V *N*-channel MOSFET (Q3)
1 6.2V 1W Zener diode (ZD1)
1 5.1V 1W Zener diode (ZD2)
2 1N4004 1A diode (D1,D2)
1 UF4007 ultra-fast 1000V diode (D3)

www.jaycarelectronics.co.uk
www.altronics.com.au

Capacitors
1 470uF 16V radial electrolytic
1 220uF 10V radial electrolytic
2 100nF 630V metallised polyester
2 100nF 100V MKT metallised polyester
2 100nF multilayer monolithic ceramic
2 1nF 100V MKT metallised polyester

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Resistors (0.5W 1% metal film unless specified)

2 10MΩ HV*		4 3.3MΩ HV*		* HV (1.6kV rated)
1 1MΩ	1 120kΩ	2 68kΩ	1 22kΩ	eg MH25 series
4 10kΩ	1 5.6kΩ	1 4.7kΩ1W	1 3.6kΩ	Farnell 110-0295
1 3.3kΩ	3 2.2kΩ	1 1.8kΩ	1 1.5kΩ	(10MΩ) and Farnell
1 1kΩ	1 680Ω	1 270Ω	1 180Ω	110-0288 (3.3MΩ)
2 100Ω	1 22Ω	1 0.1Ω 5W wirewound		

1 1MΩ mini 25T vertical trimpot (VR1)
1 10kΩ mini horizontal trimpot (VR2)

microcontroller then makes its calculations to drive the LCD.

Once it has measured and calculated the leakage current in this way, the micro can then calculate the effective leakage resistance. This is because it is able to sense the position of test voltage selector switch S1, via the contacts of S1b which are connected to input pin 17 (RA0) and pin 16 (RA7). So, knowing the test voltage in use, it can calculate the total resistance connected between the test terminals. Finally, it then works out the external resistance between the terminals by subtracting the 4.6kΩ or 14.7kΩ internal resistance.

Both of the calculated current and resistance values are then displayed on the LCD module, along with the test voltage being used.

IC3 is using its internal clock oscillator, running at very close to 8MHz. This gives an instruction cycle time of 2MHz, which may be monitored using a scope or frequency counter at test point TP2.

Trimpot VR2 allows the LCD module's contrast to be adjusted for optimum visibility, while the 22Ω resistor connected to pin 15 sets the current level for the module's inbuilt LED back-lighting. This was chosen for the best compromise between display brightness and battery life, as the LED back-lighting is a major component of total battery current.

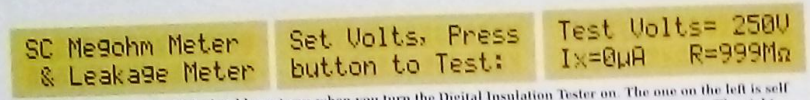
Construction

As you can see from the photos and diagrams, most of the components used in the new Digital Insulation Meter are mounted directly on two small PC boards.

The high voltage converter parts all mount on the smaller of the two boards, which measures 70mm × 51mm and is coded 850 (DC-DC Conv). This board sits in the bottom of the plastic box, at the front of the 6×AA cell batteryholder.

Most of the remaining components mount on the larger board, which measures 109mm × 94mm and is coded 849 (Mains/Dis). This board attaches to the underside of the box lid/front panel via four 25mm-long M3 tapped spacers.

The only components not mounted on either board are the test terminals, pushbutton switch S2 and power switch S3; these all mount directly on the box lid/front panel.



The three LCD screens which should greet you when you turn the Digital Insulation Tester on. The one on the left is self explanatory. It changes automatically to the middle one, which tells you what to do (it's not rocket science). The right screen shows the test voltage (as set by S1), the leakage current (in this case zero – bewdy!) and the measured resistance.

the holes using a sharp chisel or hobby knife. Then the sides of the hole can be smoothed using small needle files.

We have prepared an artwork for the front panel, which can be photocopied from the magazine (Fig.5). The resulting copy can be attached to the front of the lid and then covered with self-adhesive clear film for protection. A more robust alternative is to hot-laminate the paper panel in a clear pouch, cut it to size and then attach it using thin double-sided tape.

You might also like to attach a 60mm × 30mm rectangle of 1mm to 2mm thick clear plastic behind the LCD viewing window, to protect the LCD from dirt and physical damage. The 'window pane' can be attached to the rear of the lid using either adhesive tape or epoxy cement.

Once your lid/front panel is finished, you can mount switches S2 and S3 on it using the nuts and washers supplied with them. These can be followed by the binding posts used as the meter's test terminals. Tighten the binding post mounting nuts quite firmly, to make sure that they don't come loose with use. Then use each post's second nut to attach a 4mm solder lug, together with a 4mm lockwasher to make sure these don't work loose either.

Now you can turn the lid assembly over and solder 'extension wires' to the connection lugs of the three switches, and also to the solder lugs fitted to the rear of the binding posts. These wires should all be about 30mm long and cut from tinned copper wire (about 0.7mm diameter).

Once all of the wires are attached, they should be dressed vertical to the lid/panel so they'll mate with the corresponding holes in the main PC board when the two are combined.

You should now be ready for the only slightly fiddly part of the assembly operation: attaching the main PC board assembly to the rear of the lid/front panel.

This is only fiddly because you have to line up the extension wires from switches S2, S3 and the two test terminals with their matching holes in the PC board, as you bring the lid and board together. This is not too difficult though, so just take your time and the lid will soon be resting on the tops of the board mounting [illegible]. Then you can secure the [illegible] 6mm-long machine [illegible]

Turn the [illegible] and solder each of the [illegible] minal extensions to the copper pads. Then trim off the excess wire.

The final assembly step is to connect the four wires used for the interconnections between the PC boards, and also the ends of the battery holder leads to the terminal pins on the lower end of the main board. The interconnecting leads connections are shown clearly in Fig.3, but there are two points which should be stressed. One is that while light-duty insulated hookup wire (even rainbow cable, which we used) is fine for the three low voltage leads (+9V, GND and Vb), you *must* use wire with mains-rated insulation for the high voltage lead.

The second point is that although this is not shown in Fig.3 for clarity, all four of the interconnecting leads are run underneath the main board, and connect to it on the copper side.

Note too that although the high voltage lead connects to a terminal pin on the converter board, it solders directly to the board copper on the main board end. A terminal pin can't be used here, because it would protrude down too far when everything is assembled (and risk shorting over to one of the cells in the battery holder).

Once the interconnecting leads and battery leads have been fitted, your [illegible] Meter is almost ready for initial checkout. All that remains is to make sure power switch S1 is in the Off position, and then fit six 1.5V alkaline (or lithium) cells into the batteryholder.

Another view of the completed PC boards, ready for installation in the case. The smaller board (above) is actually an early prototype – there are a few differences in the final version (shown in the overlay).

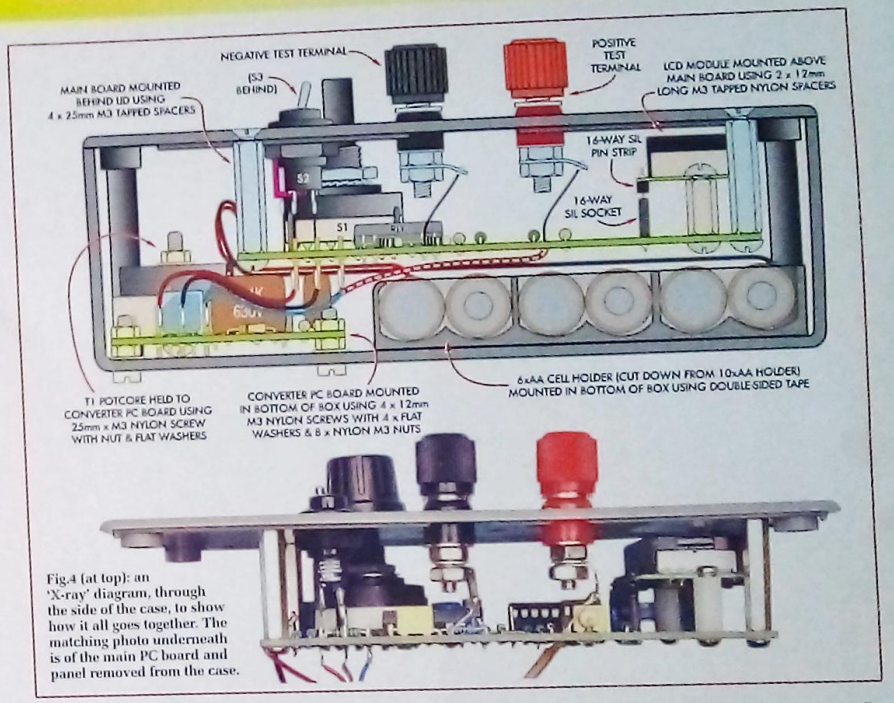

NEGATIVE TEST TERMINAL
(S3 BEHIND)
POSITIVE TEST TERMINAL
LCD MODULE MOUNTED ABOVE MAIN BOARD USING 2 x 12mm LONG M3 TAPPED NYLON SPACERS
MAIN BOARD MOUNTED BEHIND LID USING 4 x 25mm M3 TAPPED SPACERS
16-WAY SIL PIN STRIP
16-WAY SIL SOCKET
S2
S1
T1 POTCORE HELD TO CONVERTER PC BOARD USING 25mm x M3 NYLON SCREW WITH NUT & FLAT WASHERS
CONVERTER PC BOARD MOUNTED IN BOTTOM OF BOX USING 4 x 12mm M3 NYLON SCREWS WITH 4 x FLAT WASHERS & 8 x NYLON M3 NUTS
6 x AA CELL HOLDER (CUT DOWN FROM 10 x AA HOLDER) MOUNTED IN BOTTOM OF BOX USING DOUBLE-SIDED TAPE

Fig.4 (at top): an 'X-ray' diagram, through the side of the case, to show how it all goes together. The matching photo underneath is of the main PC board and panel removed from the case.

The location of all of the components mounted on both boards, along with their correct orientation, should be clear from the overlay diagram, Fig.3.

There are only two wire links to be fitted to each board, so these are best soldered first so they won't be forgotten. After both pairs of links are in place, you can fit the terminal pins on the larger board: test points TP1 and TP2 and their reference grounds, plus those for the 9V battery connections (at lower left) and the three at lower right for the interconnections to the converter board.

There are a further six terminal pins to fit on the smaller board: for TP3 and its ground, the three interconnection wires to the larger board (at lower right) and finally for the high voltage output (upper left). Once the terminal pins have been fitted, you can fit the sockets for IC1 (on the smaller converter board), IC2 and IC3.

Next, come all of the fixed resistors, taking particular care to fit each value in its correct position. Follow these with the two trimpots, making sure you fit these with the orientation shown in Fig.3.

The capacitors are next, starting with the lower value ceramic and metallised polyester caps and following these with the 1nF (on the converter board) and the two polarised electrolytics on the main board – again matching their orientation to that shown in Fig.3. The 100nF 630V polyester caps can be fitted also at this stage.

After the capacitors, you can fit diodes D1 and D2 on the main board, and D3 (UF4007) on the converter board, taking care to orient them as shown in Fig.3. These diodes can then be followed by Zener diodes ZD1 and ZD2, which both go just above the centre of the main board. Note that these are oriented in opposite ways, as shown in Fig.3, and also that the 6.2V Zener is ZD1 while the 5.1V Zener is ZD2.

Now you can solder transistors Q1 and Q2 to the converter board, making sure that you fit the BC337 device as Q1. You can also fit the remaining BC327 transistor (Q4) on to the main board.

After the transistors, you can fit reed relay RLY1, making sure you position it with the 'notch' end uppermost, as indicated in Fig.3. Then comes the rotary switch (S1), after first cutting its spindle to a length of about 15mm from the threaded mounting sleeve, and filing off any burrs.

Mount the switch in the board so that it is oriented with the locating spigot in the '5 o'clock' position, and push the switch pins through the board holes as far as they'll go before soldering to the pads underneath.

Once the switch is fitted, you should remove its main nut/lockwasher/position stopwasher combination and turn the spindle by hand to make sure it's at the fully anticlockwise limit. Then refit

The complete set of voltages corresponding to all eight possible binary codes is given in Table 9.2.

Binary-weighted DAC

An improved binary-weighted DAC is shown in Fig.9.5(b). This circuit operates on a similar principle to that shown in Fig.9.5(a), but uses four analogue switches instead of a four-bit data latch. The analogue switches are controlled by logic inputs so that a switch's output is connected to the reference voltage (V_{ref}) when its respective logic input is at logic 1, and to 0V when the corresponding logic input is at logic 0.

When compared with the previous arrangement, this circuit offers the advantage that the reference voltage is considerably more accurate and stable than using the logic level to define the analogue output voltage. A further advantage arises from the fact that the reference voltage can be made negative, in which case the analogue output voltage will become positive. Typical reference voltages are –5V, –10V, +5V and +10V.

Unfortunately, by virtue of the range of resistance values required, the binary-weighted DAC becomes increasingly impractical for higher resolution applications. Taking a 10-bit circuit as an example, and assuming that the basic value of R is 1kΩ, the binary weighted values would become:

Bit 0 1kΩ
Bit 2 2kΩ
Bit 3 4kΩ
Bit 4 8kΩ
Bit 5 16kΩ
Bit 6 32kΩ
Bit 7 64kΩ
Bit 8 128kΩ
Bit 9 256kΩ

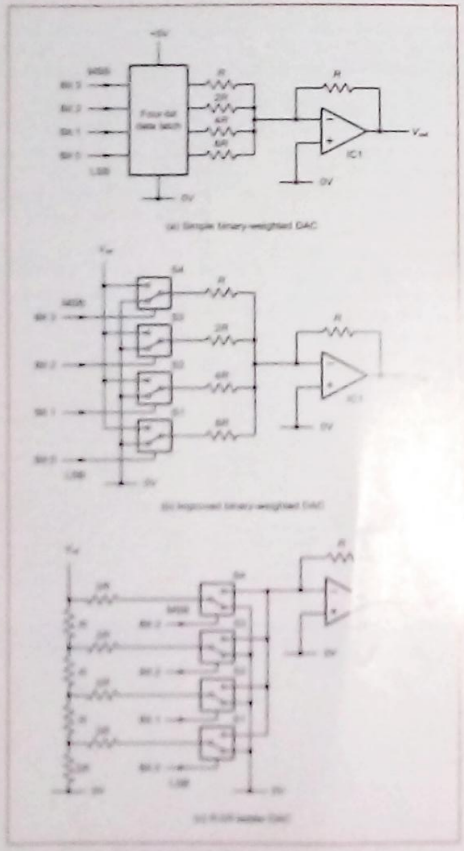


Fig.9.5. Simple DAC arrangements

Table 9.2. Output voltages produced by the simple DAC shown in Fig.9.5(a)

Bit 3	Bit 2	Bit 1	Bit 0	Output voltage
0	0	0	0	0V
0	0	0	1	-0.625V
0	0	1	0	-1.250V
0	0	1	1	-1.875V
0	1	0	0	-2.500V
0	1	0	1	-3.125V
0	1	1	0	-3.750V
0	1	1	1	-4.375V
1	0	0	0	-5.000V
1	0	0	1	-5.625V
1	0	1	0	-6.250V
1	0	1	1	-6.875V
1	1	0	0	-7.500V
1	1	0	1	-8.125V
1	1	1	0	-8.750V
1	1	1	1	-9.375V

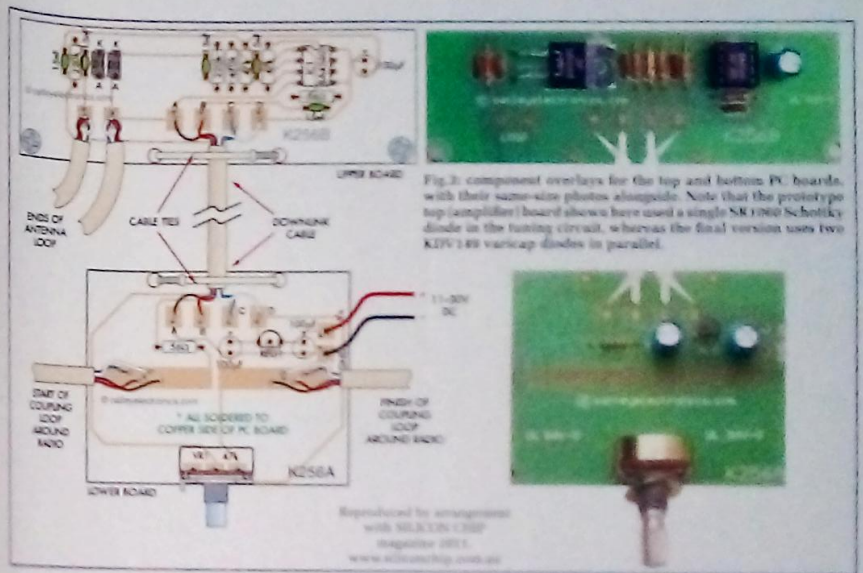


Fig.3: component overlays for the top and bottom PC boards, with their same-size photos alongside. Note that the prototype top (amplifier) board shown here used a single SR1000 Schottky diode in the tuning circuit, whereas the final version uses two KDV149 varicap diodes in parallel.

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stations – induce tiny electric currents at numerous frequencies.

The tuned circuit, consisting of X-frame-mounted coil loops, in parallel with a variable capacitance (we'll explain how this is achieved in a moment), effectively filters out almost all of these currents, except for the ones which correspond to the resonant frequency. The resulting narrow band of signals is then fed into an amplifier, based on op amp IC1a.

The amplified signals are then fed to another coil, this one designed to wrap around the AM receiver. This loop re-radiates the signal so that the ferrite rod aerial coil inside the radio can receive it again and process the signal, just as it would any other radio signal it receives.

What we are doing, therefore, is essentially 'preconditioning' the signal, so that the radio itself doesn't have to try hard to extract the wanted signal.

Remember those three things we mentioned earlier, which determine a receiver's performance? Well, this circuit not only boosts the signal level, making the receiver more sensitive to weak signals, but also adds another stage of filtering, making the receiver more selective. As a result, the performance must be better – and in fact can be markedly better!

To keep interference to a minimum, the X-frame loop antenna itself should be mounted outside the home, well away from motors, switches or other sources of interference.

Variable tuned circuit

As you probably know, you can make a tuned circuit's basic frequency variable by varying either the inductance or capacitance (remember that formula earlier?).

In general, it's a lot easier to adjust the capacitance, although many multi-band radio receivers do change coils (inductance) when switching bands.

We could use a small variable tuning capacitor, but these are not only hard to get, they're also getting rather expensive. The miniature ones commonly sold these days are incredibly fiddly to use and not at all conducive to tracking down weak radio signals!

But there is another way to obtain a variable 'capacitor'. Many semiconductors exhibit a change in capacitance when the voltage across them is changed. Varicap diodes are one such device, and in this circuit, we have

Deflection and an effective antenna configuration

The original circuit (developed by Oatley Electronics) used a single SR1000 Schottky diode as the variable capacitance diode, and this covered just the 900kHz to 1800kHz end of the broadcast band. This device is shown in the photos, but was subsequently replaced by two KDV149 varicap diodes, enabling the entire broadcast band to be covered.

Note: if you don't want to build a large wooden antenna mast, you can achieve similar results by winding 10 turns of wire (spaced about 10mm apart) on a plastic hobby storage box (or crate) measuring about 300 × 390 × 280mm deep.

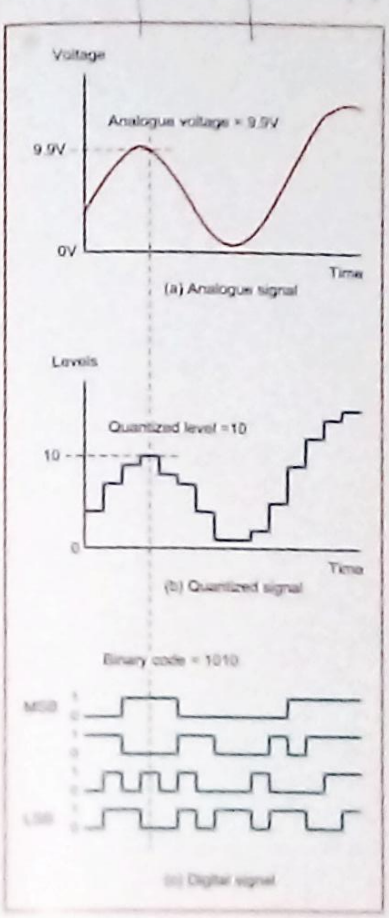


Fig. 9.1. The process of quantising an analogue signal into its digital equivalent

into voltage levels by sampling at regular intervals (t_1, t_2, t_3, etc).

Digital-to-analogue conversion

The basic digital-to-analogue converter (DAC) has a number of digital inputs (often 8, 10, 12, or 16) and a single analogue output, as shown in Fig.9.4. The simplest form of DAC shown in Fig.9.5(a) uses a set of binary-weighted resistors to define the voltage gain of an operational summing amplifier and a four-bit binary latch to store the binary input while it is being converted.

Note that, since the amplifier is connected in inverting mode, the analogue output voltage will be negative rather than positive. However, a further inverting amplifier stage can be added at the output to change the polarity if required.

The voltage gain of the inputs to the operational amplifier (determined by the ratio of feedback to input resistance and taking into account the inverting configuration) is shown in Table 9.1. If we assume that the logic levels produced by the four-bit data latch are "ideal" (such that logic 1 corresponds to +5V and logic 0 corresponds to 0V), we can

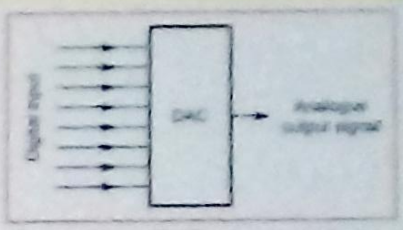


Fig.9.4. Basic DAC representation

determine the output voltage corresponding to the eight possible input states by summing the voltages that will result from each of the four inputs taken independently.

For example, when the output of the latch takes the binary value 1010 the output voltage can be calculated from:

$$V_{out} = (-1 \times 5) + (-0.5 \times 0) + (-0.25 \times 5) + (-0.125 \times 0) = -6.25V$$

Similarly, when the output of the latch takes the binary value 1111 (the maximum possible) the output voltage can be determined from:

$$V_{out} = (-1 \times 5) + (-0.5 \times 5) + (-0.25 \times 5) + (-0.125 \times 5) = -9.375V$$

Table 9.1 Table of voltage gains for the simple DAC shown in Fig.9.5(a)

Bit	Voltage gain
3 (MSB)	$-R/R = -1$
2	$-R/2R = -0.5$
1	$-R/4R = -0.25$
0 (LSB)	$-R/8R = -0.125$

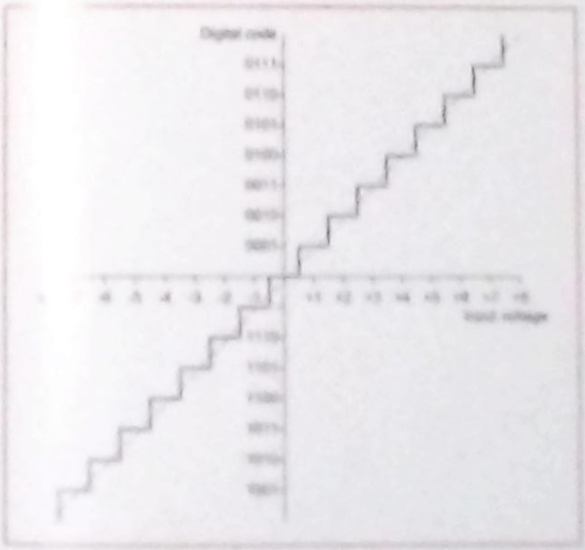


Fig.9.2. Quantisation levels for a simple ADC that uses a four-bit binary code

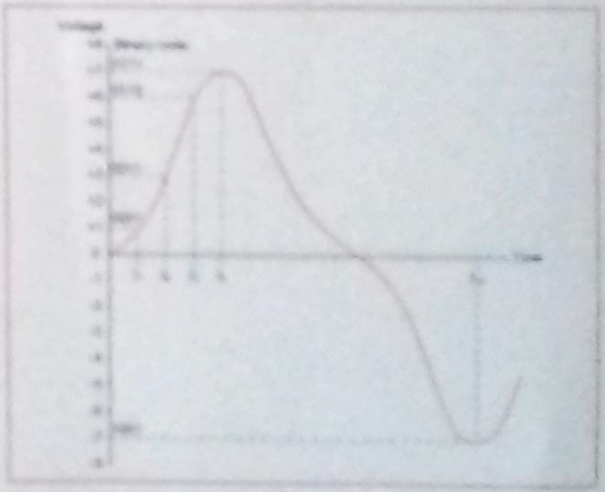


Fig.9.3. An analogue signal quantised into voltage levels by sampling at regular intervals (t_1, t_2, t_3, etc.)

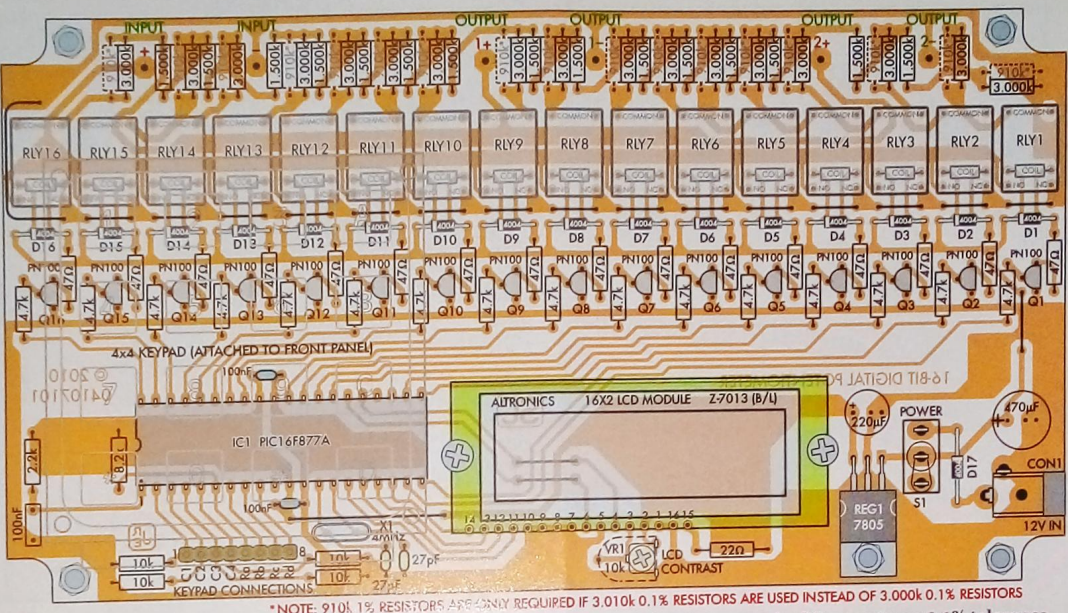


Fig.5: install the parts on the PC board as shown in this overlay diagram and the photo ooverleaf. Be sure to use 0.1% tolerance resistors as specified in the R/2R ladder (910kΩ, 3.000kΩ and 3.000kΩ types) – see parts list.

The display on the LCD module shows the unit's status in each operating mode. When you are keying in a new output (or input) voltage, it displays the digits as you enter them.

In the normal mode, where the divider is set to provide a specific output voltage, it displays that voltage along with the assumed input voltage. Or, if you have toggled the divider's output off, it displays 'OFF' to remind you that there is currently zero output.

All the control circuitry operates from an external 12V DC supply, which can be a 12V battery or plugpack. The maximum current drawn is about 360mA when all 16 relays are switched on (ie, when the output

This drops to
e relays are all
OFF).
ated directly
via series diode
olarity protec-
uit (IC1 and the
om a regulated
+5V rail derived from the 11.4V line via a 7805 3-terminal regulator (REG1).

The only other items to mention are the 4MHz crystal X1 (used for IC1's clock oscillator); trimpot VR1, which sets the contrast of the LCD module; and the 22Ω resistor connecting to pin 15 of the LCD module. The latter sets the current for the LCD module's LED backlighting.

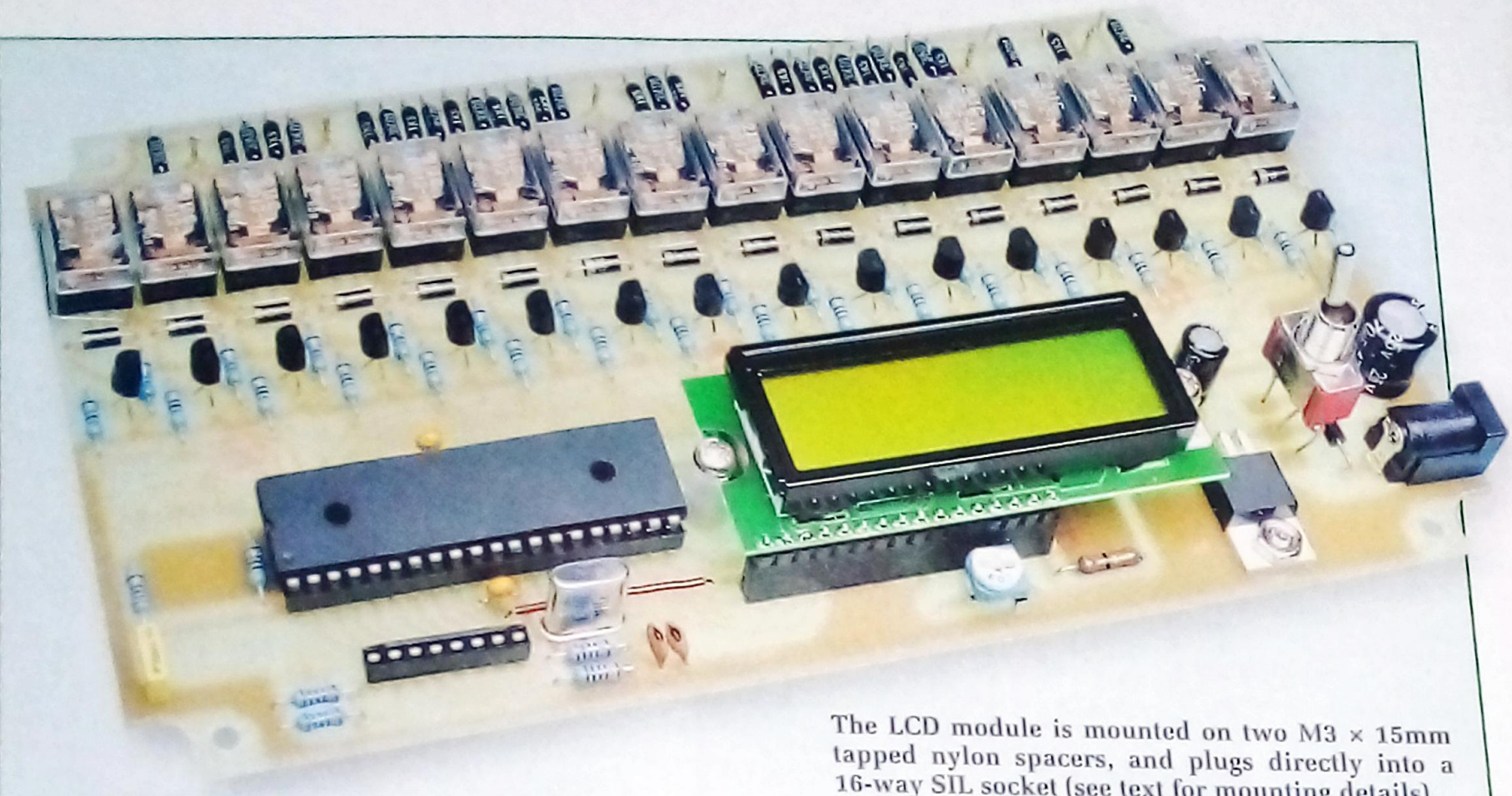
Construction

The *Digital Potentiometer* is fairly easy to build, with almost all components mounted directly on a single PC board, coded 856. Measuring 184mm × 99.5mm, this PC board is available from the *EPE PCB Service*. The board assembly fits snugly inside a standard UB2-size plastic box measuring 197mm × 113mm × 63mm. It mounts on the rear of the box lid on four M3 × 25mm tapped spacers.

The only parts not mounted directly on the PC board are power switch S1, the 4 × 4 keypad and the six binding posts. These all mount on the box lid, which forms the front panel.

Table 1: Resistor Colour Codes

No.	Value	4-Band Code (1%)	5-Band Code (1%)
4	10kΩ	brown black orange brown	brown black black red brown
1	8.2kΩ	grey red red brown	grey red black brown brown
16	4.7kΩ	yellow violet red brown	yellow violet black brown brown
17	3.000kΩ	not applicable	not applicable
1	2.2kΩ	red red red brown	red red black brown brown
15	1.500kΩ	not applicable	not applicable
16	47Ω	yellow violet black brown	yellow violet black gold brown
1	22Ω	red red black brown	red red black gold brown



The LCD module is mounted on two M3 × 15mm tapped nylon spacers, and plugs directly into a 16-way SIL socket (see text for mounting details).